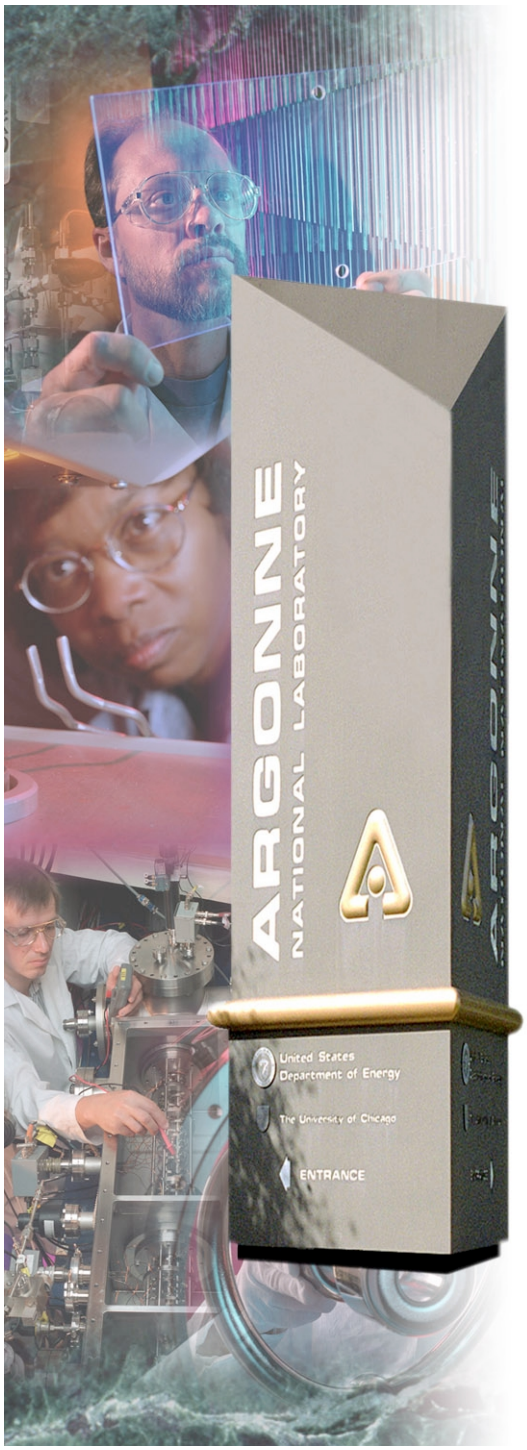

DANESS
Dynamic Analysis of Nuclear Energy System Strategies

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A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

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- **Background**
- **DANESS**
  - Architecture
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Objective

- *An easy-to-use and quick tool for the technical-economic assessment of nuclear energy systems in a macro-economic energy development context*

Scope:

- *Integrated process model of nuclear energy systems*
- *PC/Mac platform, < 15 min calculation time*
- *For use by experts, consultants, policy-makers, students, …*

Background

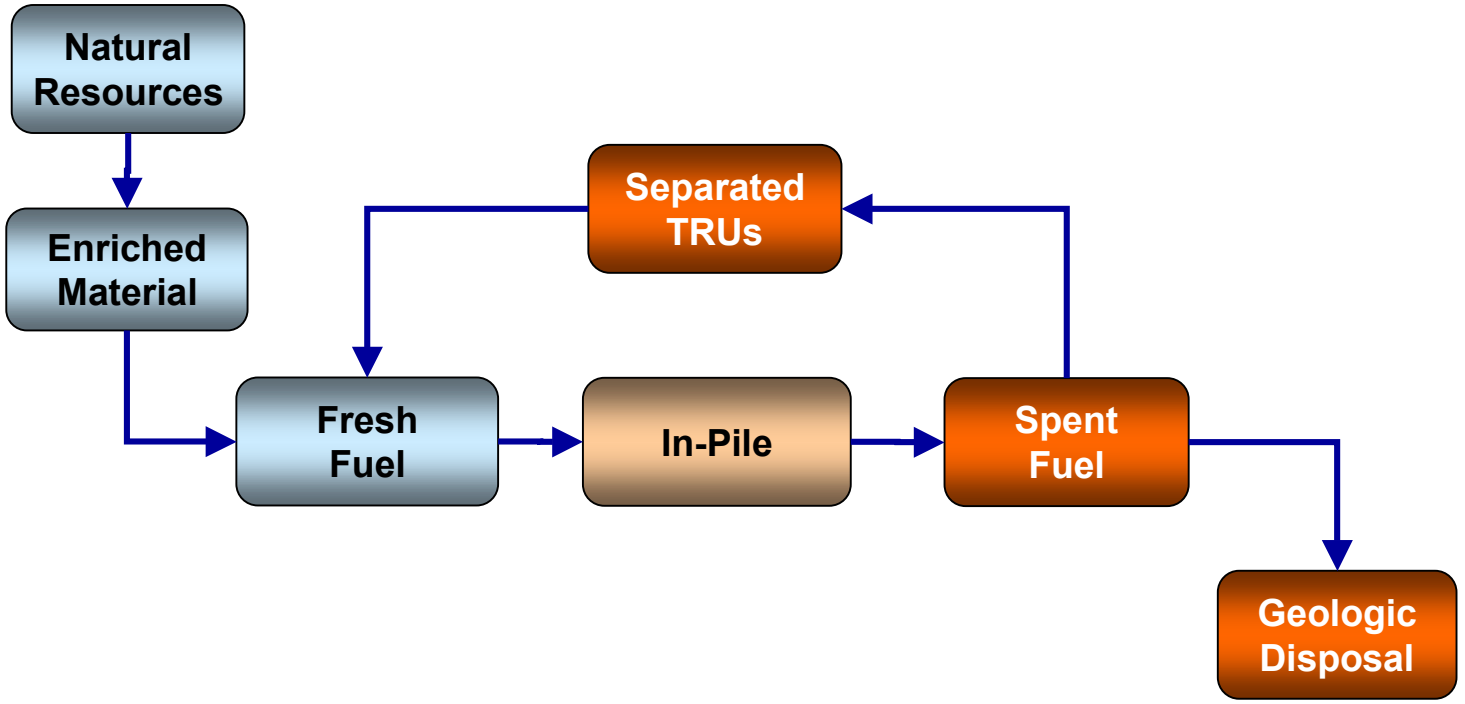
- **Market**
  - Future of nuclear power ? Economics
  - Government actions ? Direct / indirect policy tools
  - Increasing LCA / Externalities approach
- **Technology Roadmaps**
  - Interest for symbiotic nuclear energy systems
  - Technical and economic assessment
- **R&D management**
  - Parameter scoping for R&D resource allocation

Integrated Process Model (IPM) needed

Several initiatives asked for a nuclear IPM development

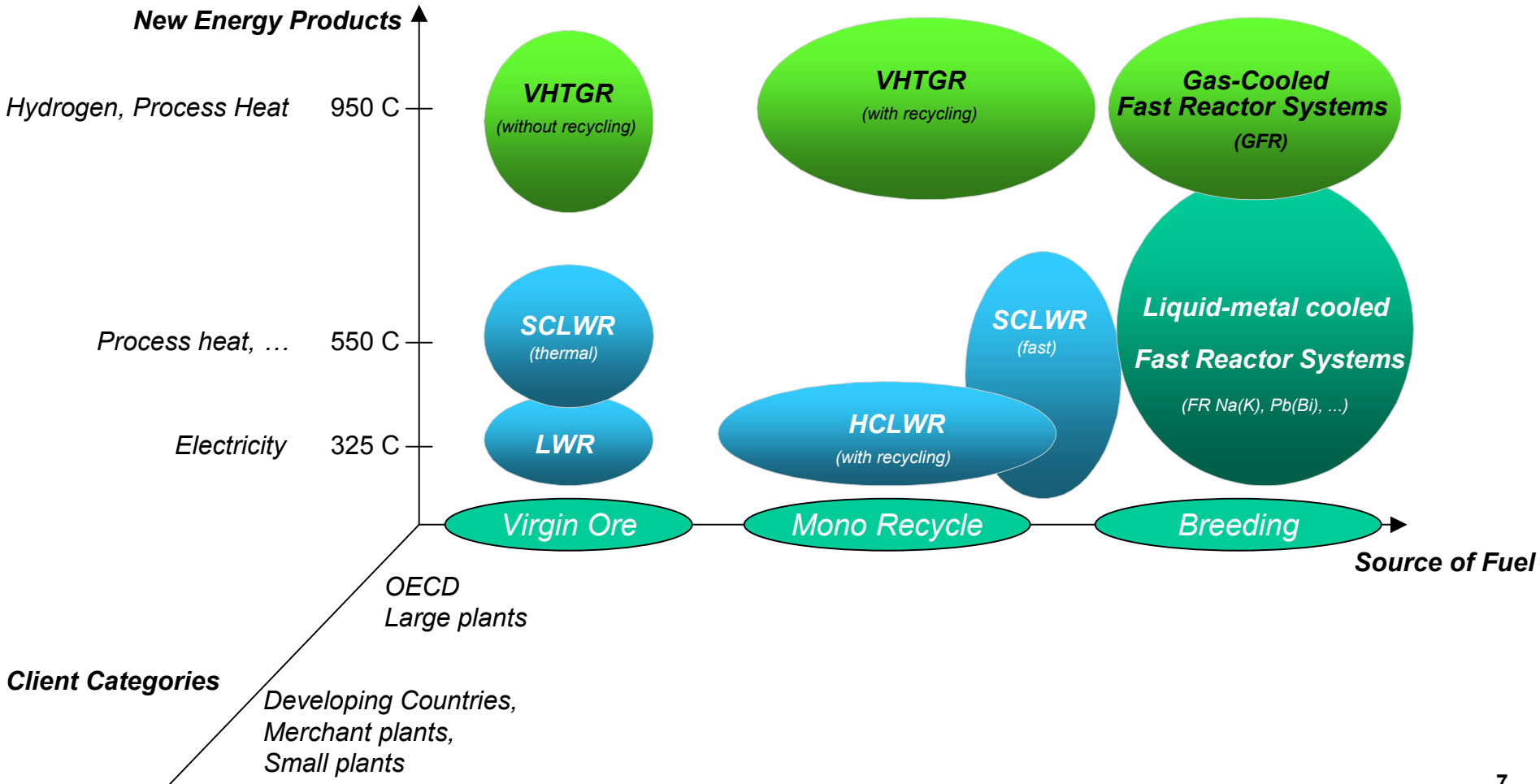
- **Generation-IV**
  - Fuel Cycle Cross-Cut Group
    - *DYMOND (ANL)*
- **Advanced Fuel Cycle Initiative**
  - Evaluation of different Tier-1 and Tier-2 options
- **OECD/NEA, '*Comparative assessment of ADS and FR in advanced nuclear fuel cycles*', 2002**
- **MIT, '*The Future of Nuclear Power*', July 2003**
  - "*The DOE R&D program should … establish a large nuclear system analysis, modelling, and simulation project, including collection of engineering data, to assess alternative nuclear fuel cycle deployments*"
- **EC 6th FWP**
- **Industry**

Many options exist for nuclear energy system design



- A lot of studies exist to approach this from a purely physics point-of-view
  - Mainly in equilibrium situation
- Only recently, growing interest for an economic point-of-view in a deregulated market

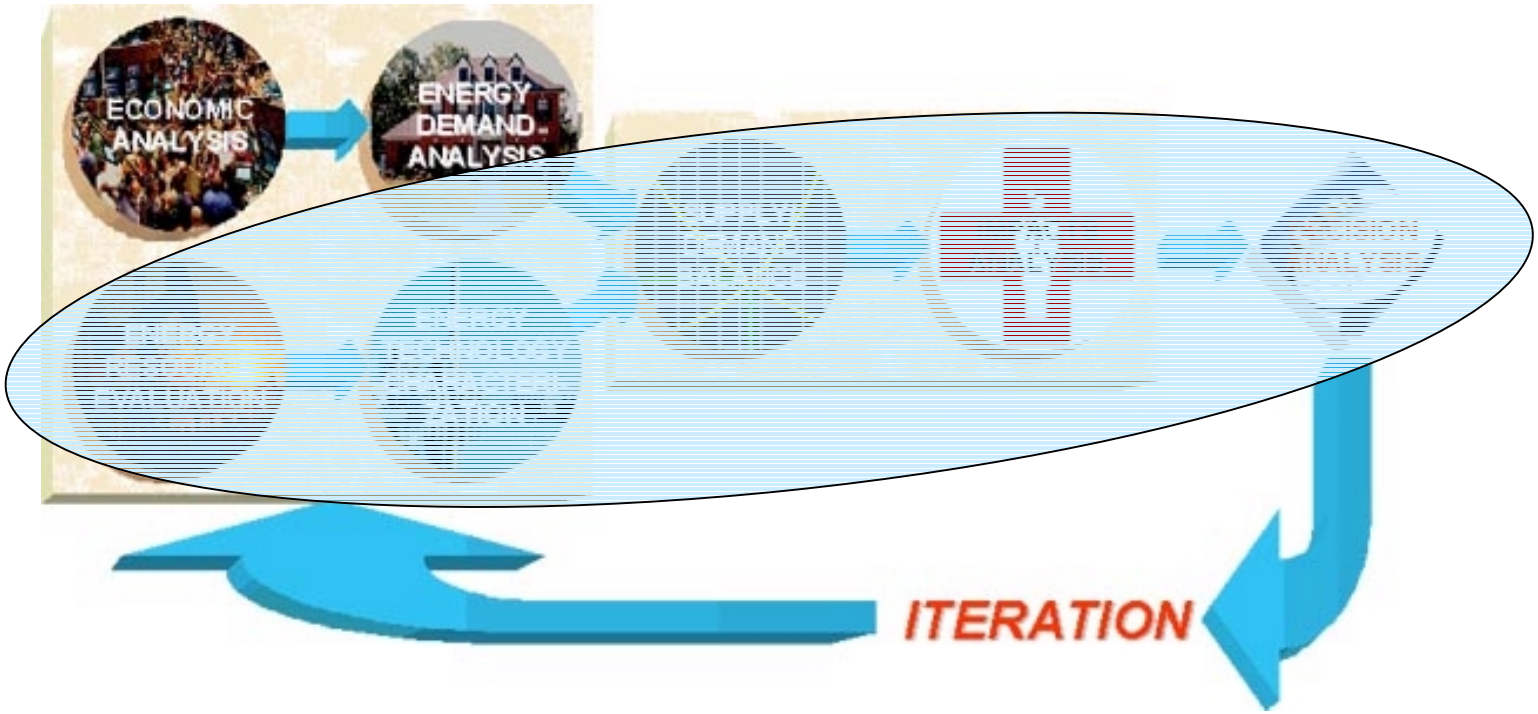
Evolving Role for Nuclear Energy



DANESS scope

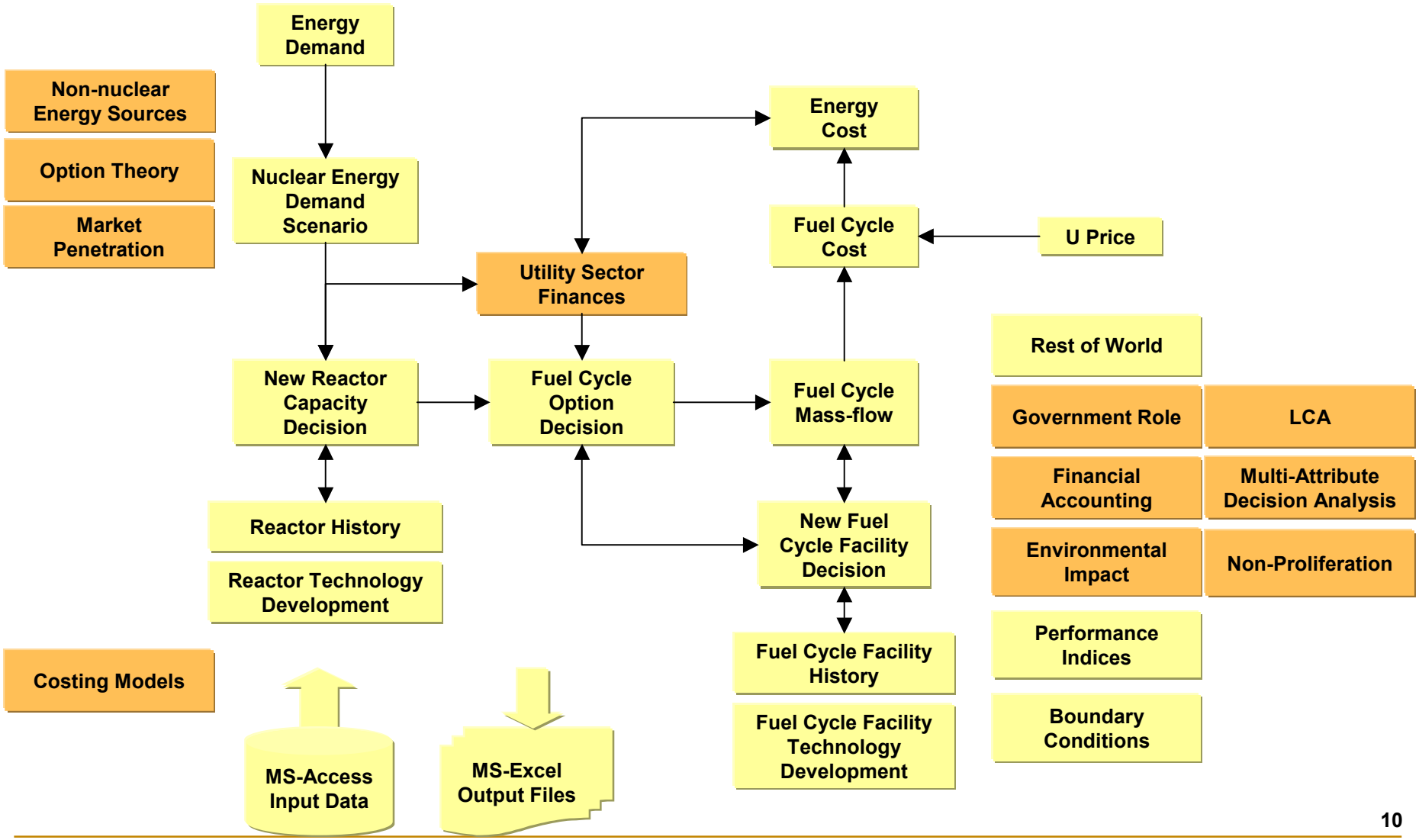
- **Energy demand driven**
- **Multiple reactors, fuels and fuel cycle facilities**
  - Flexible combination of reactors and fuels allowing simulation of symbiotic nuclear energy systems
  - Different fuel cycle options varying in time
  - Fissile material feedback
- **Full fuel cycle mass-flow analysis**
- **Economics**
  - Capital, O&M and Fuel Cycle costs
- **Intra-nuclear market penetration model**
- **Other models**
  - *Technology development*
  - *Learning curve*
  - *…*

Positioning



- **Integrated nuclear process model**
- **Communication tool !**
  - Fast, easy-to-use, transparent !

DANESS Architecture



Simulation features

- **Discrete simulation of nuclear energy systems, i.e.:**
  - Fuel loading per batch
  - Distinction initial core loads and reloads
  - Time-lags in fuel cycle
  - Time-lags in ordering, building … decommissioning reactors, fuel cycle plants, …
  - Periodic financial accounting
  - Forecasting of fuel / fissile material needs
  - …

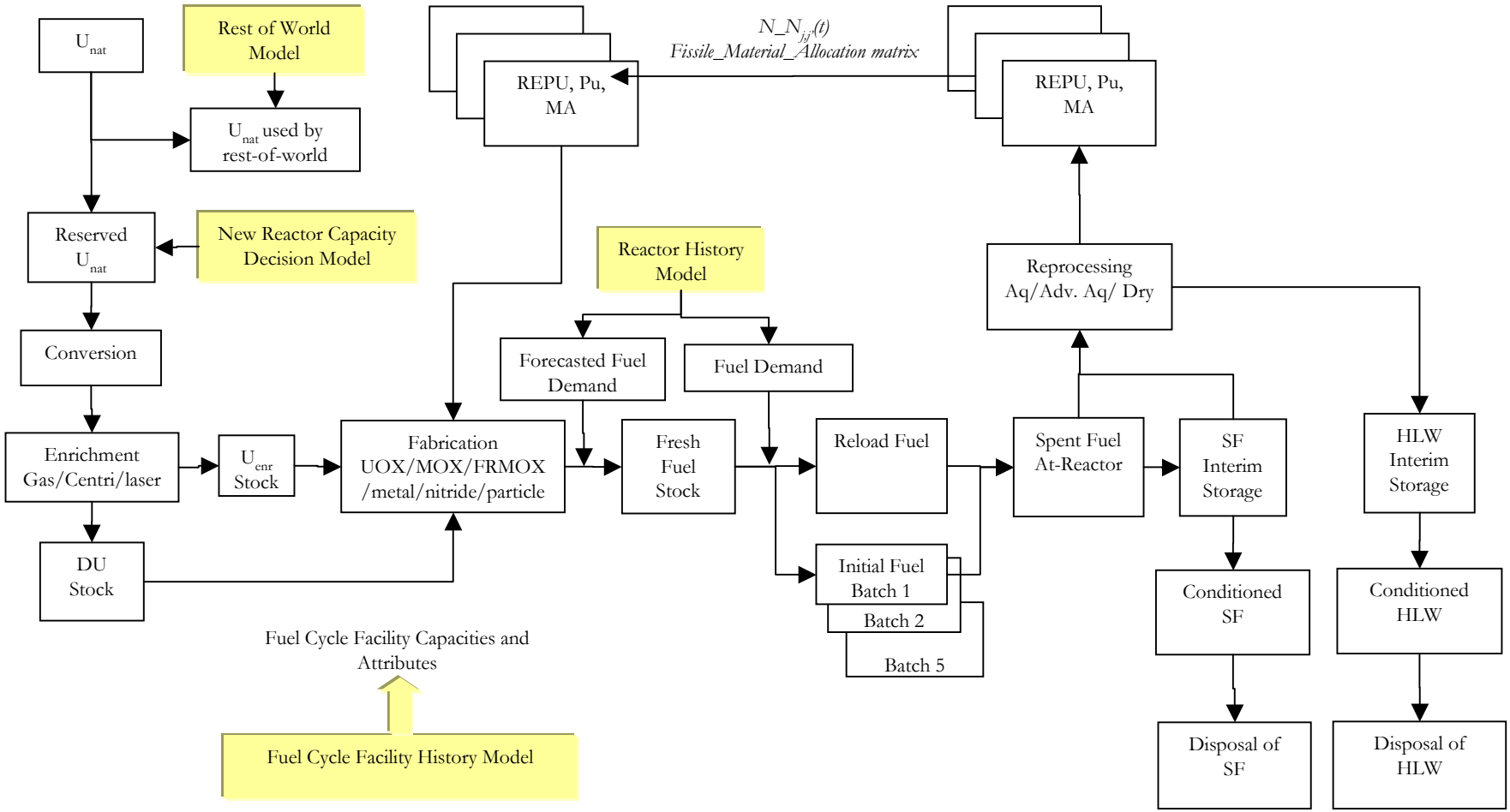
Energy Demand Driven

- **Energy demand driven dynamic analysis of nuclear energy systems**
  - Energy demand by:
    - *World, Region, Country*
    - *According to IIASA/WEC, IAEA/NEA scenarios, user-defined*
- **Initial conditions**
  - Existing reactor park based on IAEA/NEA RDS-1 and Brown Book data (annually updated)
    - *Attribute Database for reactor types (AGR, BWR, FR, GCR, HTGR, HWGCR, HWLWR, LWGR, PHWR, PWR, SGHWR, WWER, GFR, LMR, ADS, …)*
    - *Attribute Database for fuel cycle facilities*

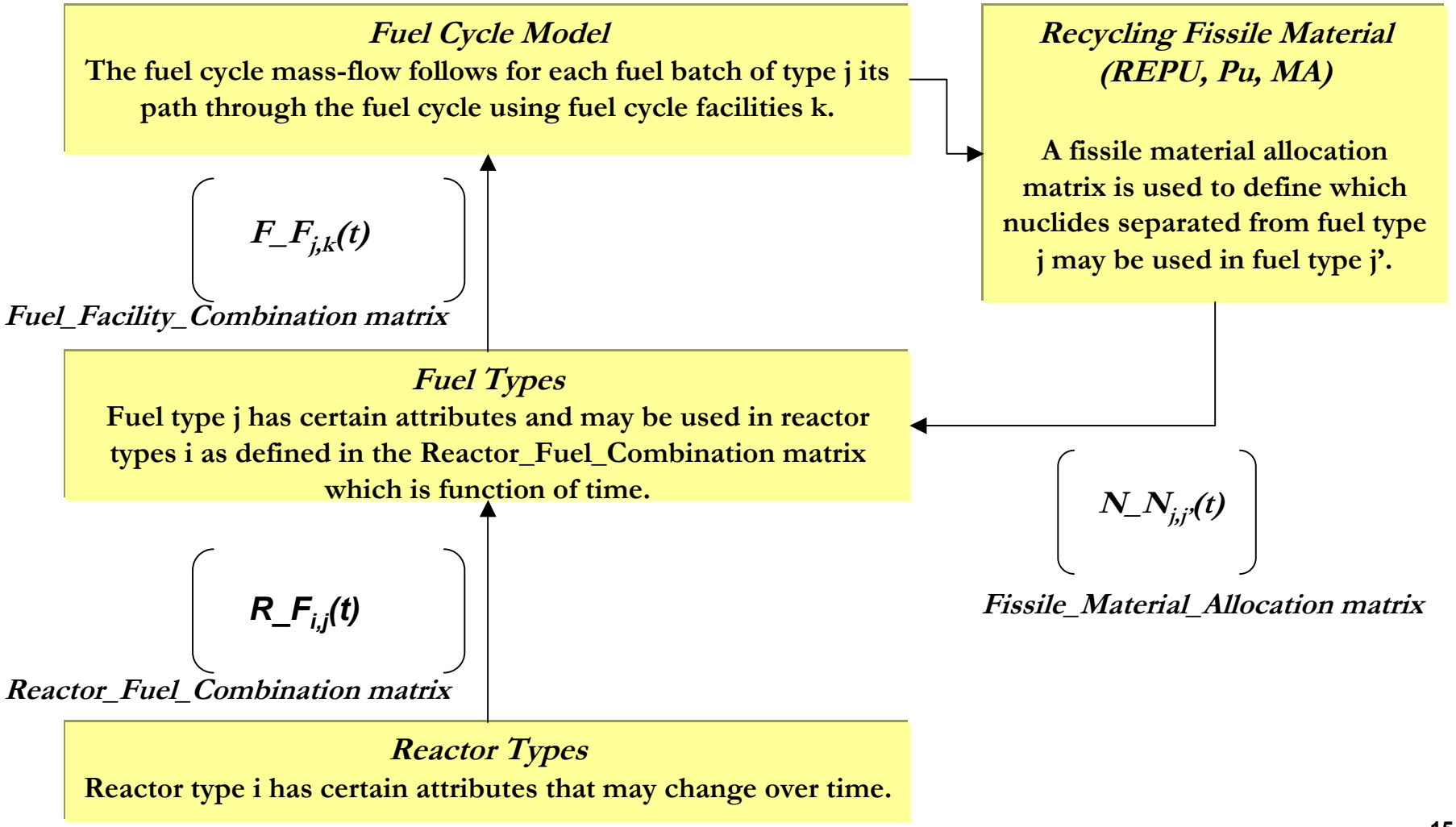
Reactor & Fuel Cycle Model

- **Current development version allows:**
  - To model 20 reactor types & 20 fuel types
    - *In time-varying reactor/fuel combinations*
  - Following reactor history per reactor type
  - Analysis of equilibrium as well as initial reactor fuel loading
  - To follow fuel cycle operations (21 steps) for each fuel batch per fuel type
  - Cross flow of fissile materials between fuel types
  - Each fuel type may vary in fuel cycle option
  - To follow U, DU, REPU, Pu, MA (Np, Am, Cm), FP (SLFP, LLFP) inventories

Fuel Cycle Model



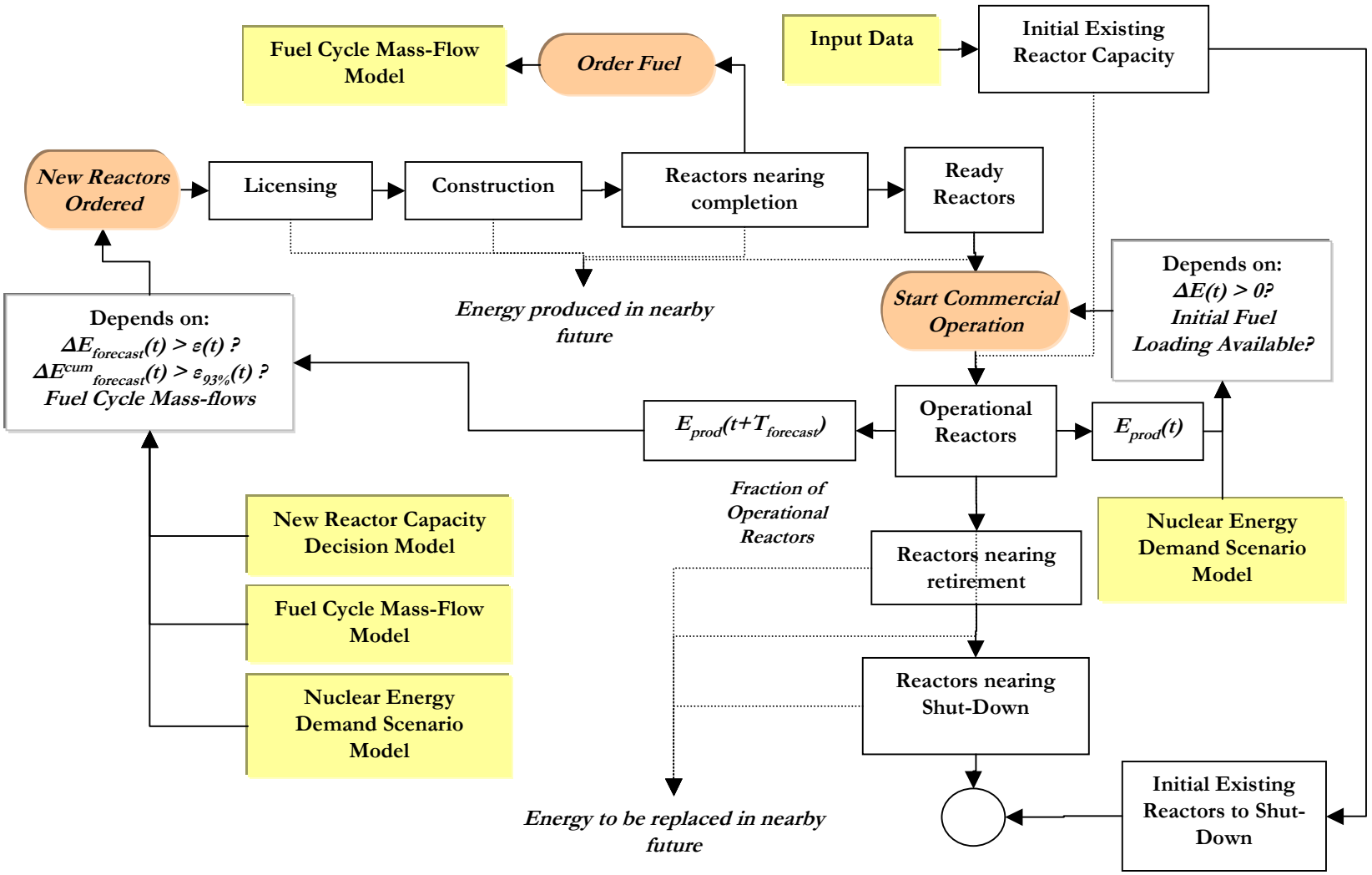
Reactor, fuel and fuel cycle are uncoupled (allows symbiosis)

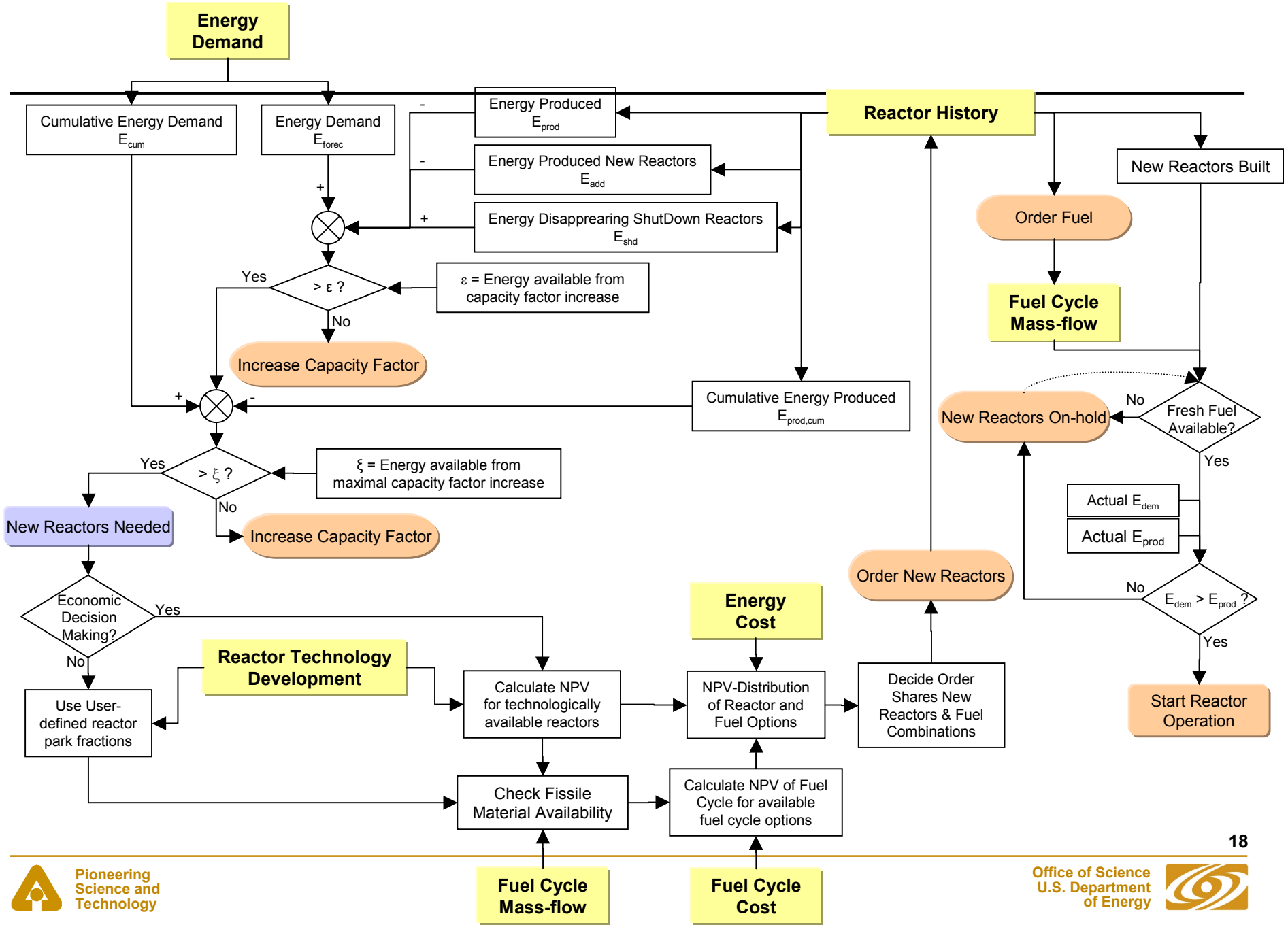


New Reactors Decision Making

- **New reactors may be ordered as function of:**
  - Possible increase load-factor operational reactors
  - Technological availability of reactors
  - Availability of fissile material
  - Economic performance
  - Investment potential utility sector

Reactors follow a life path



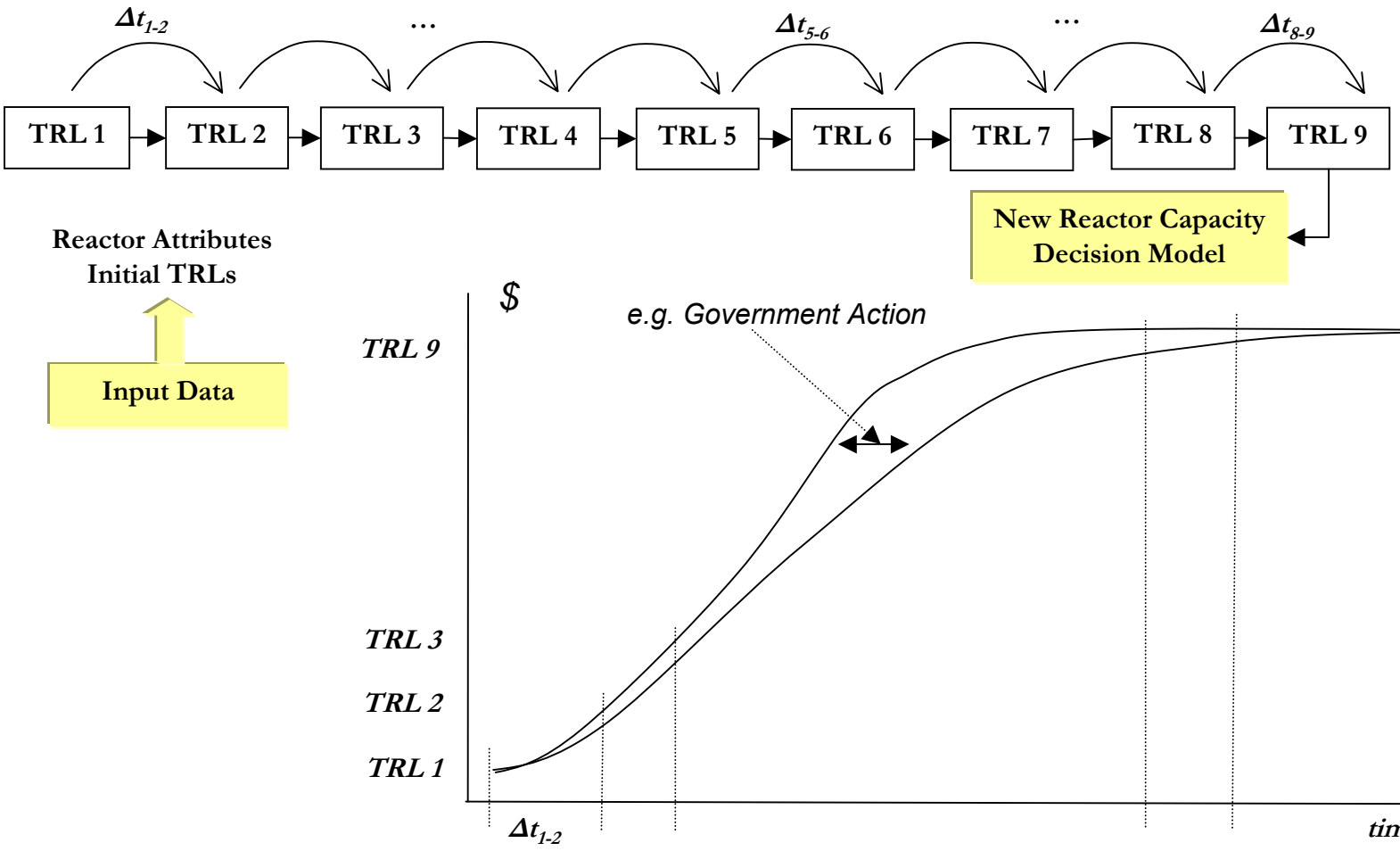

Energy Demand
Cumulative Energy Demand E_{cum}
Energy Demand E_{forec}
Energy Produced E_{prod}
Energy Produced New Reactors E_{add}
Energy Disappearing ShutDown Reactors E_{shd}
Reactor History
New Reactors Built
Order Fuel
Fuel Cycle Mass-flow
> ε ?
ε = Energy available from capacity factor increase
Increase Capacity Factor
Cumulative Energy Produced $E_{prod,cum}$
New Reactors On-hold
Fresh Fuel Available?
> ξ ?
ξ = Energy available from maximal capacity factor increase
New Reactors Needed
Increase Capacity Factor
Actual E_{dem}
Actual E_{prod}
Order New Reactors
$E_{dem} > E_{prod}$?
Economic Decision Making?
Energy Cost
Reactor Technology Development
Calculate NPV for technologically available reactors
NPV-Distribution of Reactor and Fuel Options
Decide Order Shares New Reactors & Fuel Combinations
Start Reactor Operation
Use User-defined reactor park fractions
Check Fissile Material Availability
Calculate NPV of Fuel Cycle for available fuel cycle options
Fuel Cycle Mass-flow
Fuel Cycle Cost

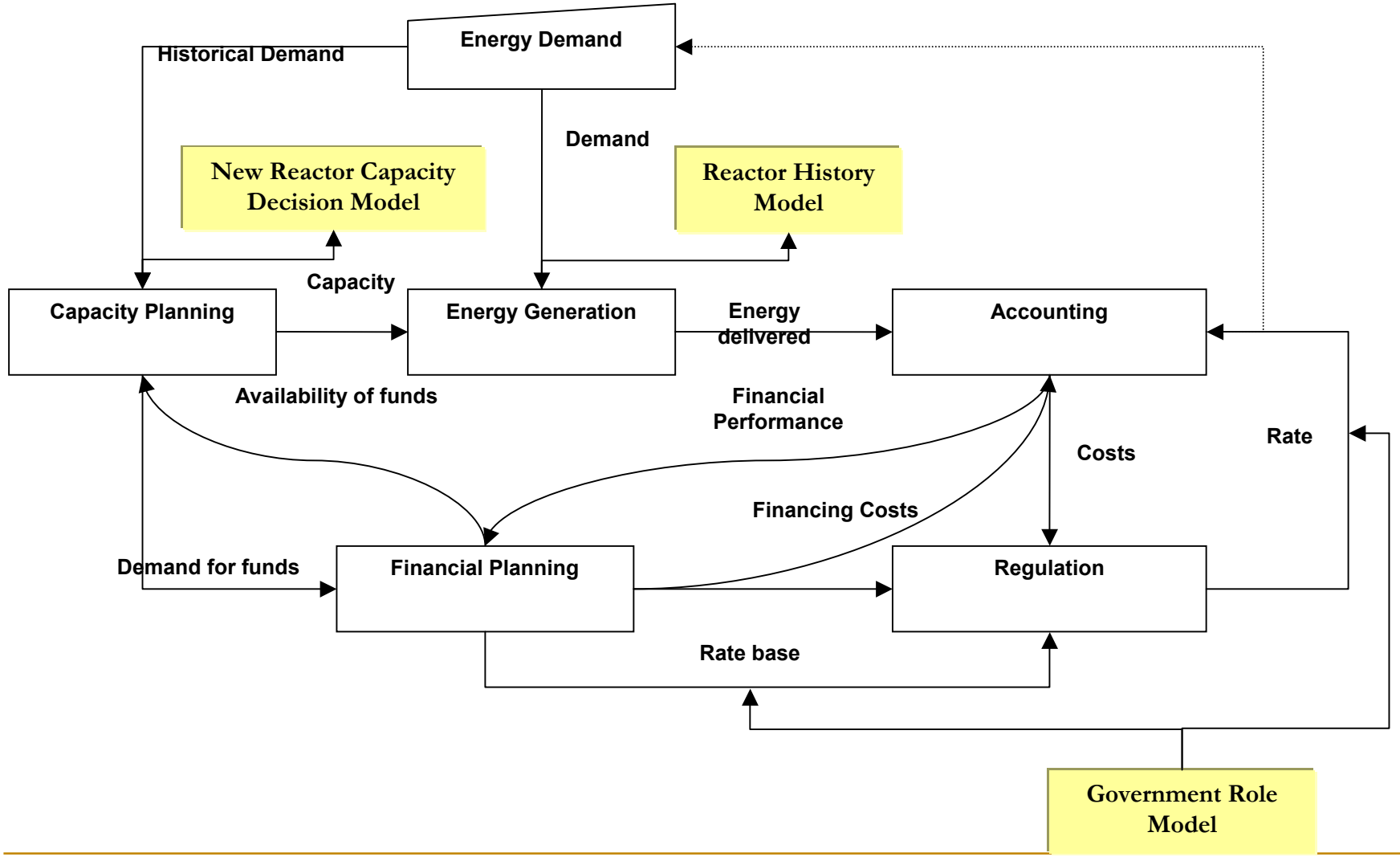
Economics

- **Actual energy costs ($/kWh)**
- **(Net) Present Values**
  - Account of federal, state, local, sales taxes
  - Capital
    - *Construction*
    - *Capital charges*
    - *Other (overnight) costs*
    - *Decommissioning*
    - *Contingencies*
  - O&M
  - Fuel Cycle
    - *Owning or leasing fuel*
    - *Waste fees*
- **Financial Accounting keeps track of the revenues and expenses for each reactor, facility and owner**

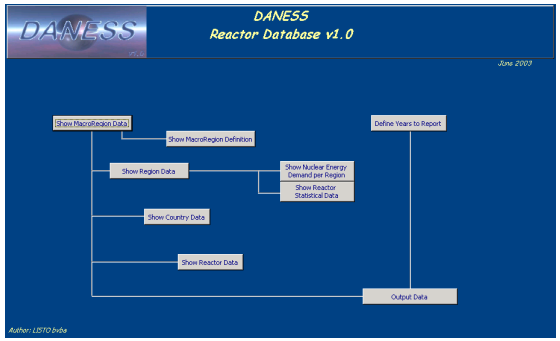
Other parts of the code

- **Experience curves**
  - Cost, timing, losses
- **Inventories**
  - In cycle, reactor, disposal
- **Environmental impact**
  - Natural resources (LCA)
  - Secondary waste
  - Radiological Impact
- **Non-proliferation**
- **Competition with other energy sources**
- **Link with macro-economic models**
  - Market penetration

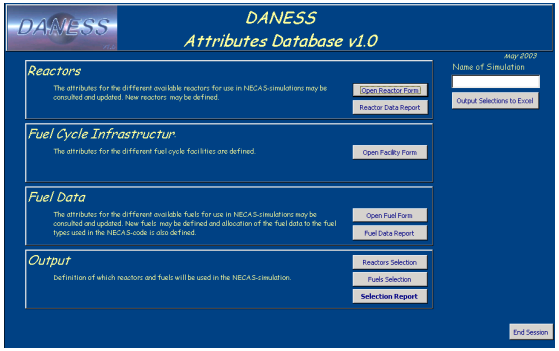

Δt_{1-2}
…
Δt_{5-6}
…
Δt_{8-9}
TRL 1
TRL 2
TRL 3
TRL 4
TRL 5
TRL 6
TRL 7
TRL 8
TRL 9
New Reactor Capacity Decision Model
Reactor Attributes
Initial TRLs
Input Data
$
e.g. Government Action
TRL 9
TRL 3
TRL 2
TRL 1
Δt_{1-2}
time


Energy Demand
Historical Demand
Demand
New Reactor Capacity Decision Model
Reactor History Model
Capacity
Capacity Planning
Energy Generation
Energy delivered
Accounting
Availability of funds
Financial Performance
Costs
Rate
Financing Costs
Demand for funds
Financial Planning
Regulation
Rate base
Government Role Model

Coupled databases



- **History of existing and planned reactors**
  - Including statistics
  - Annually updated



- **Attributes of reactors, fuels and fuel cycle facilities**
  - Including references
  - Regularly updated

Validation

- **Three distinct steps:**
  - *Verification of calculations*
    - < 1 % error-margin with identical input-data
    - < 5 to 15 % error-margin
  - *Verification*/Benchmarking of separate sub-models
  - Continuous benchmarking with other codes

Fuel cycle cost ($mills_{1991}$/kWhe)	NEA	DANESS	Difference (%)
Once-through fuel cycle	5.46	5.31	-2.7
Front-end	4.70	4.52	-3.8
Back-end	0.76	0.79	+3.9
Credits	0.0	-	
Pu mono recycle fuel cycle	6.23	5.85	-6.1
Front-end	4.70	4.27	-9.1
Back-end	1.79	1.58	-11.7
Credits	-0.26	-	-

Intended Use

- Analysis of development paths for nuclear energy
- Integrated process model
- Parameter scoping for new designs
- Economic analysis of nuclear energy systems
- Government role
- Educational use

Continuous Development

Users-Group

Developments

Macro-economic energy modelling

DIAS

Life-Cycle Analysis

Utility Finances / Economics

Derivatives use

Utility / Engineering

Waste Management

Repository impact

Sociology

Risk perception, NP

Conclusions

- **A new tool has been developed for the technical-economic assessments of nuclear energy systems**
  - Easy-to-use and quick
  - PC/Mac platform
  - Customizable for users
  - Extensive database support

- ***Continuous development to become a standard for technical-economic assessments of nuclear energy systems***